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Christopher Gerrard and Alejandra Gutiérrez

The *Qanat* in Spain: Archaeology and Environment

Summary

This article defines the elements of *qanat* technology in Spain and describes some recent projects which have advanced our understanding. A brief bibliography is provided that exposes some of the confusion surrounding classification, nomenclature, numbers, and distribution of the *qanat*. Some examples taken from recent fieldwork illustrate the complexities and show how different elements of hydraulic technology are combined. Hydraulic features at Citruénigo (Navarre), Bureta, Bulbueite and Daroca (all Aragón), Madrid, and Toledo (Castile-La Mancha) are all described. Finally, the paper focuses on recent research into dating these features and highlights a recently completed project that dated episodes of construction and maintenance using optically stimulated luminescence (OSL). This technique seems to offer significant potential for future research.

Keywords: *qanat*; medieval archaeology; optically stimulated luminescence; hydraulic archaeology

Dieser Artikel definiert die Elemente der *qanat*-Technologie in Spanien und beschreibt einige neuere Projekte, die unser Verständnis dort vorangebracht haben. Es wird eine kurze Bibliographie vorgelegt, die einige der Verwirrungen um die Klassifikation, Nomenklatur, Zahlen und Verteilung der *qanat* offenlegt. Einige Beispiele aus der jüngsten Feldforschung verdeutlichen die Komplexität der Anlagen und zeigen, wie unterschiedliche Elemente der hydraulischen Technologie kombiniert werden. Hydraulische Merkmale bei Citruénigo (Navarra), Bureta, Bulbueite und Daroca (alle Aragón), Madrid, Toledo (Kastilien-La Mancha) werden beschrieben. Schließlich werden jüngste Forschungen zur Datierung der *qanats* diskutiert und ein kürzlich abgeschlossenes Projekt vorgestellt, in dem Bauphasen und Phasen der Instandhaltung mittels Optisch Stimulierter Lumineszenz (OSL) datiert wurden. Diese Technik scheint ein erhebliches Potenzial für die Zukunft zu bieten.

Keywords: *qanat*; Mittelalterarchäologie; optisch stimulierte Lumineszenz; hydraulische Archäologie

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It is commonly accepted that Islamic irrigation systems with their hydraulic infrastructure of canals, diversion dams, and water-raising machines form the basis for later medieval Spanish agriculture.¹ According to this model, certain elements of irrigation technology first came to Spain as part of a technology ‘package’ in the first decades of the Arab conquest. This package was established around the great cities of Valencia, Murcia, and Toledo, where cultivars such as cotton and oranges were first planted and new models of water distribution and maintenance were practiced. One particular element of this package was the *qanat*, which was later transferred across the Atlantic and took root in the Americas; in Peru, Chile, and Mexico, among other places.

While the impact of Islam on irrigation is not in doubt, every single one of the above statements could, and should, be questioned. In this article, we examine the Spanish *qanat* in more detail, addressing some of the challenges of classification and nomenclature, and describing the preliminary results from a recent fieldwork project that is attempting to refine the chronological context.

I What is a *qanat*?

A *qanat* (also called *khattara*, *foggara*, or *karez* in other regions) is an underground tunnel, almost horizontal, which bores into an aquifer and guides the water out through an outlet, usually via a storage pond (Fig. 1). The construction process begins with the digging of a ‘mother well’ that is drilled downwards to the aquifer; other vertical breather shafts (sometimes called ‘aeration shafts’) are then excavated at regular intervals along the length of the tunnel, their function being to allow the excavated sediments and rock to be more easily removed, to provide light and air to the tunnel, to provide convenient points of access to make repairs, and sometimes to extract water along the length of the water course. In some *qanats*, a water ‘conveyor’ channel may be carved out in the center or to one side of the underground tunnel, not only creating a walking path that remains

1 Al-Hassan and Hill 1986.

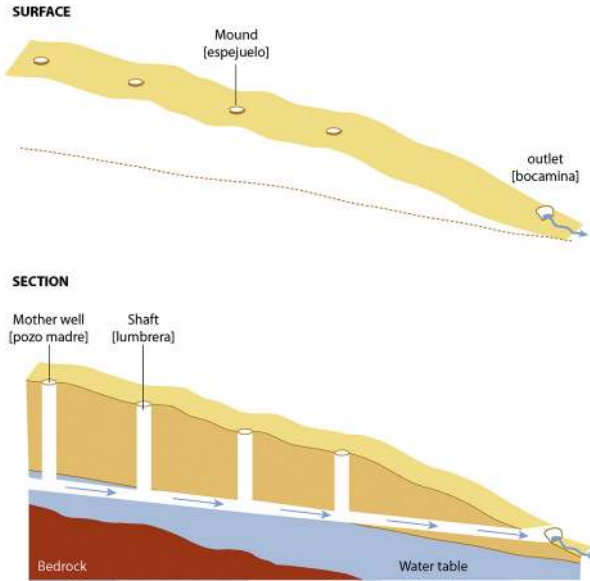


Fig. 1 A schematic view of a *qanat* as seen on the surface and as a cross section.

dry underfoot except in times of flood, but also in order to increase the speed of the water and to avoid the accumulation of sediment. Up on the surface, the distinctive feature of the *qanat* is the set of breather shafts that often have a ring of soil compacted around them (sometimes referred to as a ‘doughnut’), thereby, marking their position in the landscape, as well as serving to protect the mouths of the vertical shafts from surface flooding.

Qanats are still widely employed across the world, and are the main source of water in many communities in Oman, Afghanistan, Pakistan, China, and Azerbaijan, for example; there are more than 1500 km of *qanat* tunnels in Libya alone and perhaps 200 times that length in Iran. Unlike pumped wells, which can withdraw too much water and thereby reduce the capacity of the aquifer to supply the wells, *qanats* operate continuously and yet they cannot remove more water from the aquifer than the aquifer can naturally supply. They, therefore, offer a sustainable water supply. There are, however, some constraints: *qanats* are usually constructed in regions where the surface topography is not too mountainous and where the groundwater lies at a relatively shallow depth.

2 Research into Spanish *qanats*

Irrigation, including *qanats*, has attracted a considerable amount of interest in Spain recently. Monumental works by Pavón Maldonado, for example, provide a comprehensive

introduction to the subject, as well as multiple descriptions of so-called ‘water galleries’ from different dates, many of them repeatedly modified.² Much valuable work has also been undertaken in coastal regions in Almería by Patrice Cressier; in Valencia and Murcia by André Bazzana; and in Catalonia and Mallorca by Miguel Barceló and Helena Kirchner, where irrigation studies have a high profile inspired by earlier historians such as Thomas Glick. The list of case studies in what has been termed ‘hydraulic archaeology’ is rich and impressive.³

Most recently, a European-funded project, designed and run by geographers from Valencia University, has aimed to catalogue all the *qanats* in south-eastern Spain under the title *Foggara: Inventory, Analysis and Valorisation of Traditional Water Techniques of European and Saharan Drainage Tunnels* (2003–2007). This project comprised a bibliographic and cartographic search that produced a database and mapping of sites which have since been visited and described, thereby, creating a checklist of topographic information. Although the project was not intended to provide any historical, social, or legal context to the sites it identified, the result is a new inventory and typology of what are referred to as ‘water galleries’, which itself provides a solid basis for further research. Exceptionally useful, are the map resources provided online through the Spanish Government (Ministerio de Agricultura, Alimentación y Medio Ambiente).⁴

3 Classification and nomenclature

In Spain, *qanats* go by many names, and this is part of the confusion surrounding the true number and distribution of them across the Peninsula. They may be known as ‘water ways’ (*viajes de agua*) in the center of the country, ‘underground aqueducts’ (*acueductos subterráneos*), ‘water galleries’ (*galerías de agua*), ‘draining galleries’ (*galerías drenantes*), ‘narrow channels’ (*canalizes*), and ‘horizontal wells’ (*pozos horizontales*) in the south and south-east. In the Murcia region they are called ‘galleries with small mirrors’ (*galerías con espejuelos*), with the mirrors referring to the reflective effect of the water that is visible at the bottom of the breather shafts. Some of this terminology directly reflects the traditional names employed in 18th-century treatises (for example, when describing the “water [...] and its subterranean ways”),⁵ but also reflects recent definitions adopted by geographers, as well as translations from other languages.

2 Pavón Maldonado 1990, 185–340.

3 Cressier 1989; Cressier 1991; Cressier 2006; Bazzana and Guichard 1986; Bazzana, Guichard, and Montmessin 1987; Bazzana and Meulemeester 1998; Barceló 1989; Kirchner 2010; Glick 1970; Glick 1979; Glick 1988; Glick 1996.

4 <https://www.chj.es/es-es/ciudadano/libros/Paginas/Libros.aspx?Seccion=Cartograf%C3%ada+de+regad%C3%ados+hist%C3%B3ricos+de+regad%C3%ados+hist%C3%B3ricos> de regadíos históricos (visited on 25/05/2018); Iranzo and Hermosilla 2015.

5 Aznar de Polanco 1727, 198; Ardemans 1724, 76–77.

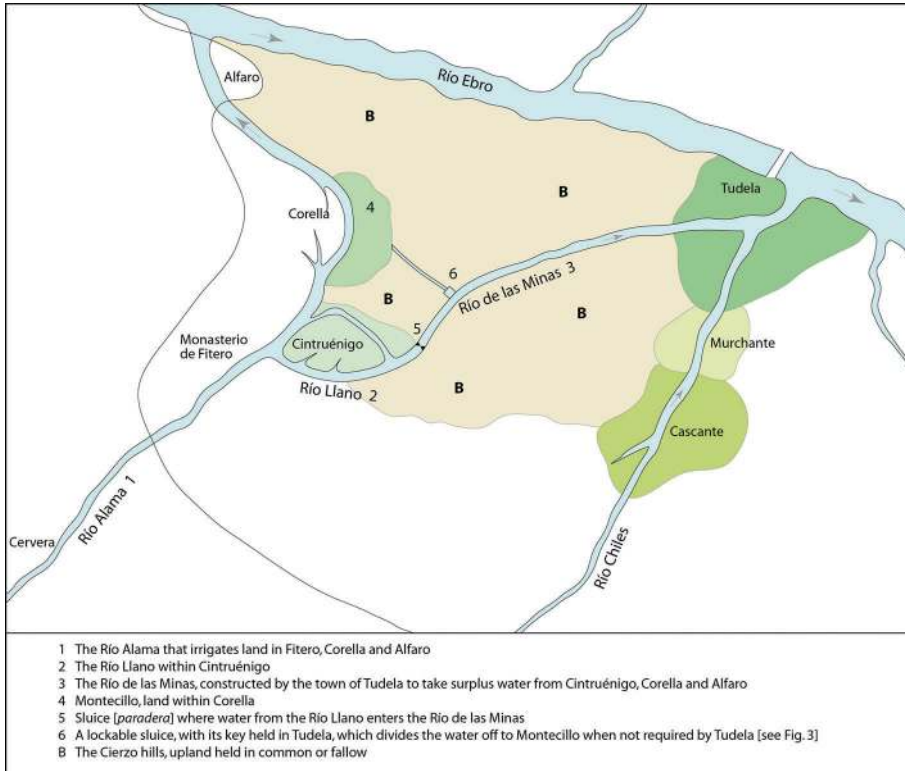


Fig. 2 Río de las Minas in Cintruénigo, Navarre, according to a map drawn before 1772 (the date when the map was donated to the Archive; *Mapas y planos de varios autores contenidos en este II tomo*, Madrid, 1798, no. 8). The 'Partidor de los Fieles' is located at number 6 (the drawing uses modern spelling).

The use of Spanish terms for *qanats* is, therefore, far from consistent. To add a further complication, some of these terms can also refer to the conveyance or transfer of water more generally; the 'water way' designed in 1772 for Hervás (Cáceres), for example, is merely the transfer of water through ceramic pipes from the spring to ponds that feed fountains in the village. The water, in this case, moves by gravity along pipes that are trenched into the ground; there is no underground tunnel.⁶ A particular source of confusion related to establishing clear definitions is the presence of vertical breather holes. While these are certainly one of the essential criteria in the identification of a true *qanat*, there are other kinds of underground tunnels with breather holes that do not drain water from an aquifer. A good illustration of this is the so-called *qanat* at Citruénigo in

6 Abujeta Martín 2010.



Fig. 3 'Partidor de los Fieles' in Cintruénigo, Navarre. Cintruénigo in the distance.

Navarre,⁷ which was constructed in the 17th century to resolve a dispute over the division of water between four neighboring communities (Fitero, Corella, Cintruénigo, and Tudela). This clash had begun centuries earlier, but in 1550, Tudela started to press in earnest for a share of the water from the irrigation channels stemming from the nearby Río Alhama, which were already in use by nearby parishes. However, it was not until 1623 that Tudela obtained permission to cut its new irrigation channel and, following further protests by neighbors wishing to protect their rights, not until 1625 was permission finally confirmed. Only then did Tudela purchase the land it needed to construct the "open and closed channels."⁸ A map, perhaps contemporary with the opening of this system or just slightly later than that, recorded all its main elements, as well as the dry land to the west of Tudela that were to be irrigated (schematized in Fig. 2). This shows that the new channel was to be called the Río de las Minas, and that it took its water from the Río Llano, an *acequia* or artificial irrigation channel that derived from the Río Alhama. In this context, it should be noted, both the 'natural' river system (the Río Alhama) and the artificially cut channels (the Llano and the Río de las Minas) use the prefix 'río' or 'river.'

On the ground today, the Río Llano is a single irrigation channel which trifurcates at a water divider called the Partidor de los Fieles (Fig. 3, number 6 in Fig. 2), with three branches running off towards Corella, Cintruénigo, and Tudela. This last branch is the Río de las Minas, dug shortly after 1625 and now referred to as a *qanat*.

In order to drive the water to the drylands in the Campo de la Sierpe on the opposite side of the Cierzo hills, where it is needed, the new channel is forced to dive

7 Hernández Charro 2006.

8 Yanguas 1823, 23–26.

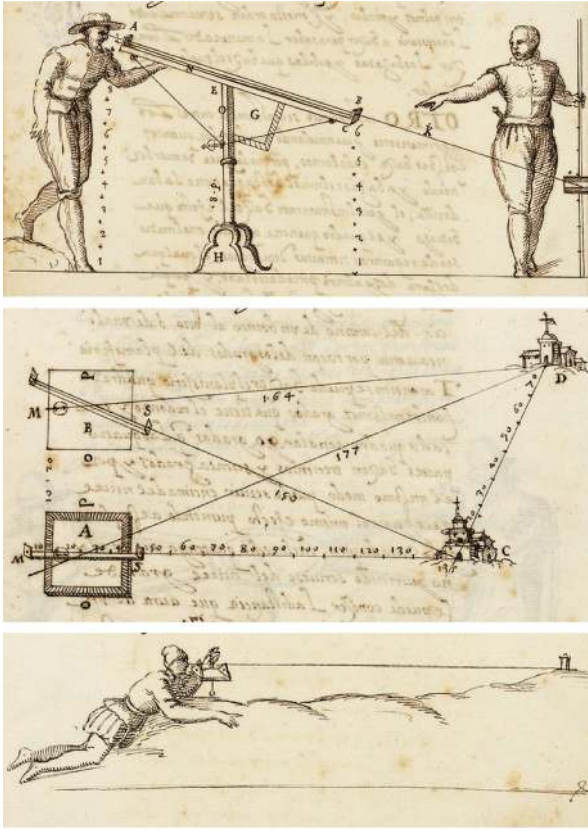


Fig. 4 How to calculate the correct level in order to convey water across the landscape in the 16th century, according to Lastanosa (1601).

underground in a tunnel for a distance of 1.5 km. There are 15 vertical shafts about 50 m apart before the water channel makes use of the interleaved hard geology and softer marls to cap its exit point (the *bocamina* in Spanish) to re-appear at El Boquerón. Here, the water is yet again divided between several channels that irrigate about 1077 hectares of olives, vineyards, and cereal fields before terminating at a reservoir (Balsa del Pulguer) close to Tudela. Although it is true that elements of the Cintruénigo water system are shared with the true *qanat*, such as the breather shafts and the underground channel, the Río de las Minas does not actually tap into the aquifer and must fall outside the strict definition of a *qanat* provided above. The construction of galleries to move water across ranges of hills in this way was already described in the 16th century, most famously by Aragonese Pedro Juan de Lastanosa (died 1576), who illustrated the method of opening the underground tunnels, here called *minas*, in his treatise on water (Figs. 4, 5, 6).⁹

⁹ Lastanosa 1601.

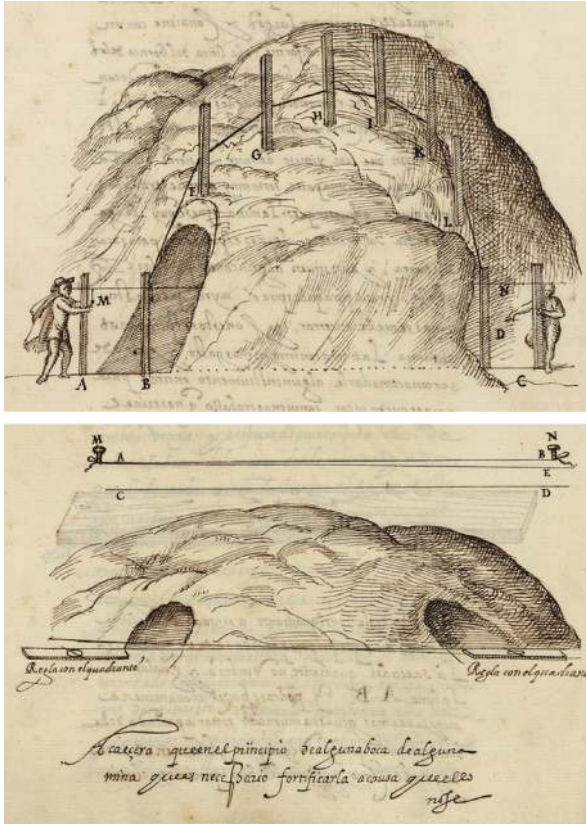


Fig. 5 How to dig a 'mine' in order to tunnel a water channel under a hill in the 16th century, according to Lastanosa (1601).

Equally common are underground galleries with shafts which tap into the water at surface level, rather than to the aquifer, in what is traditionally defined as an *adit* or 'water mine' (*mina de agua*, *minado*); confusion between these and *qanats* is quite common and the terms are sometimes used interchangeably in the literature. This is one of the *qanat*-type structures that have been documented extensively by the European *foggara* project, including some 2000 in the province of Almería alone.¹⁰ In high mountainous areas there are many *adits* or tunnels cut back into the water table, mainly short in length, but up to 820 meters in the case of 19th and 20th century examples, where there is evidence for the use of dynamite, machinery, concrete reinforcements, and modern materials. Some of these mines do have vertical shafts (called in Spanish *pozos de aireación* or *lumbrebras*); others have a mother well at the head of the *adit*, presumably to establish the depth of the water table initially before being blocked off later. Identical micro-systems

10 Hermosilla et al. 2004.



Fig. 6 How to line the tunnel in the ‘mine’ in the 16th century, according to Lastanosa (1601).

targeting particular points in the water table have been documented in the Alpujarras area, where true *qanats* are also unknown.¹¹ Those in the Alpujarras are dated to the 15th century, and some of the water cisterns associated with these systems have 16th century graffiti.¹²

‘Water-mining’ is documented in the Roman, Islamic, and later periods, and *adits* like these were still being built in Spain as late as 1969.¹³ Manuals of the 20th century describe the ideal conditions for digging a ‘water mine’: an underground gallery about 1.80 m high by 0.80 m width to allow for comfortable access, an inclination between 1 and 5/1000, with shafts (*lumbreras*) every 40 to 70 m to remove the excavated soil.¹⁴ While

11 Cressier 1989.

Gil Meseguer 2015.

12 Cressier 1985.

14 Murcia Viudas 1958, 90.

13 For example in López Fernández, Gómez Espín, and

the *adits* are, in themselves, quite simple applications of mining technology, they could also be combined with other features: at Vélez-Málaga (Málaga) the water system served the Islamic city until the 18th century and included wells, storage cisterns (*aljibes*), and galleries cut into the rock and built in brick.¹⁵ Mines were also used to bring water to the royal palace at Aranjuez (Madrid) and to its extensive gardens; the renovation works ordered by King Phillip V in the middle of the 18th century were well documented at the time and have been investigated archaeologically in considerable detail.¹⁶ *Adits* were excavated at the site of four natural springs, first by digging a channel in the bedrock, then using ceramic pipes; the first part of the channel had a brick floor, barrel vault and shaft holes capped by a shaped ashlar stone (with a cubic or pyramidal form). The holes are of different sizes, the smaller ones probably being used merely to check water levels, or for obtaining water samples to test for purity. The system was opened in 1751, flooded and repaired in 1753.¹⁷

Underground tunnels with breather holes were already being built in the Roman period. Some are even mentioned in Islamic texts from the mid-10th century, where they are described as ‘ancient’ works; examples are known at Badajoz and Jerez.¹⁸ One of the better-known Roman case studies is that at Mérida (Badajoz), but others include Albarracín (Teruel), Osma and Tiermes (both Soria), and Huelva.¹⁹ Most of these underground galleries form a part of larger, more complex systems of water transfer that may include aqueducts; in these cases, the underground galleries have barrel-, pointed- or flat-vaulted ceilings, and are generally lined with ashlar and other traditional Roman building techniques, such as *opus caementicium* and *opus signinum*. The presence of hydraulic features of Roman manufacture or even Roman settlements nearby helps date them. Segóbriga (Saelices, Cuenca) has been excavated, revealing buried features and materials associated with its construction and use in the 1st–2nd centuries AD.²⁰ Shorter *adits*, generally without breather holes and without a ‘mother well’, and terminating at a storage pond, can also date to the Roman period; in some cases they are spatially associated with Roman farmsteads or villas, such as in Granada.²¹

The general technology for the construction of underground galleries was clearly linked to mineral mining and it was long-lived, re-appearing periodically in written documents and manuals, albeit with a range of different purposes in mind.²² The ‘mine’ at Daroca (Zaragoza), for example, was built in 1555–1560 by Frenchman Pierre Vedel to collect and drive floodwater safely away from the town (Fig. 7).

15 Cabello Lara 2011.

16 Martínez Calvo and López Jiménez 2012.

17 Martínez Calvo and López Jiménez 2012, 45.

18 Khalaf Ibn Hayyān 1981; Muñoz Vicente 1991.

19 Chamizo and S. Rodríguez 2009; Ezquerro Lebrón

2007; García and Rufete 1996; García Merino 2007; Martínez 2007.

20 Morín de Pablos 2014, 213–237.

21 Bertrand and Sánchez Viciano 2009, 159.

22 For example Cuchí Oterino et al. 2006.

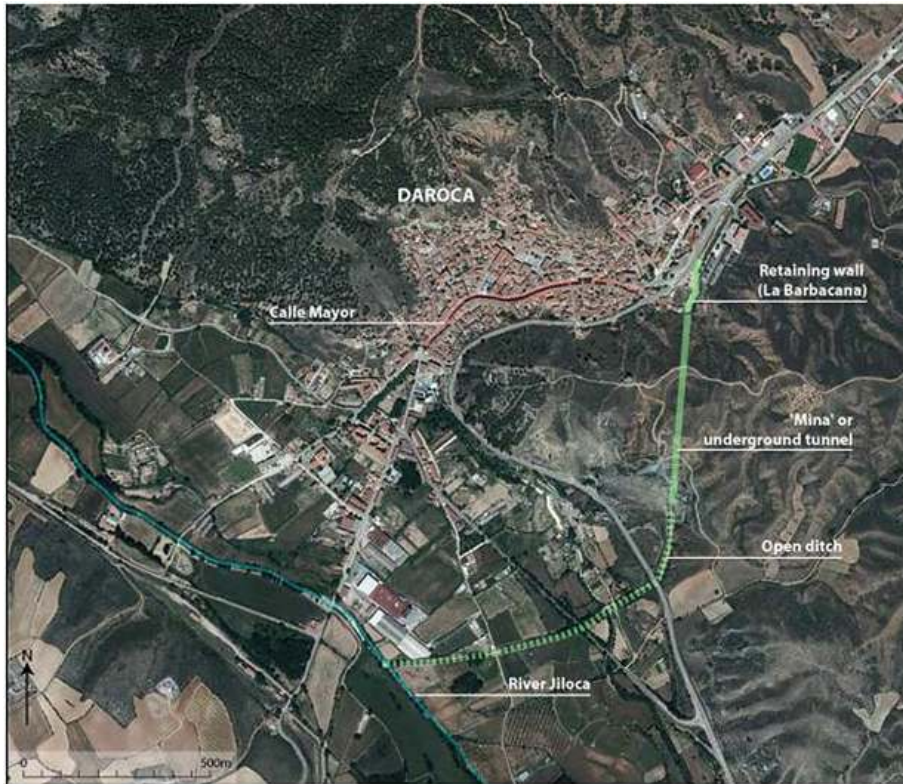


Fig. 7 The 'mine' at Daroca (Zaragoza), built in 1555–1560 to collect and drive floodwater safely away from the town.

Daroca's houses lay at the end of a ravine and the town had expanded from the hill slopes down onto the dry river plain and up onto the facing hill, where the Franquería quarter had been built around a main street (Calle Mayor). Although this is an arid region (ca. 393 mm precipitation per year), which suffers from drought, in times of very heavy rain and hail between June and September the area is affected by flash floods, so much so that by the mid-16th century the Calle Mayor was occasionally converted into a dangerous water channel, which was a threat to people and their houses. The purpose of Vedel's underground channel was therefore to divert the surface flow back to the river (Fig. 8).

To do this, a 300 m long retaining wall, called La Barbacana, was constructed to deflect water into a 900 m long tunnel that was carved right through the hill of San Jorge and down into the River Jiloca. At more than 8 m wide and 9.5 m high, the 'mine' took 5 years to complete and involved the manual excavation of some 30 000 cubic

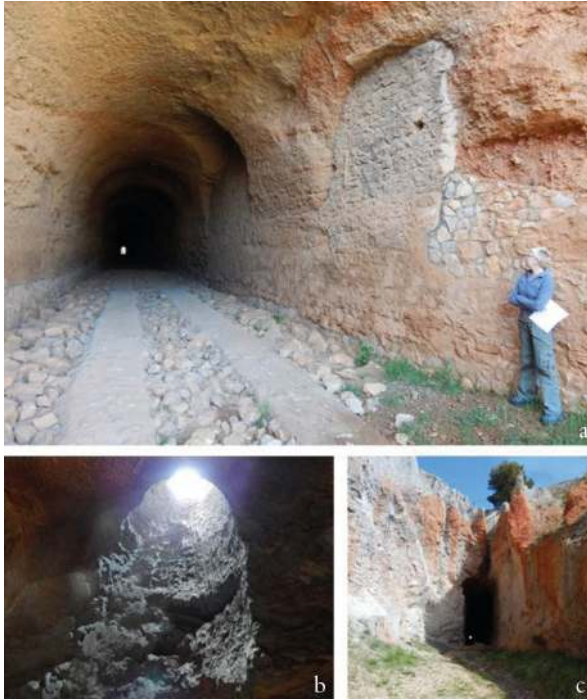


Fig. 8 The 'mine' at Daroca (Zaragoza): (a) start of tunnel, (b) shaft, and (c) tunnel exit.

meters of soil and rock.²³ In its day, the mine was something of an attraction and the diarist Henry Cock, an archer in the Flemish royal guard, described how the gallery was visited by King Philip II and his family during their trip through Aragón in 1585.²⁴ The Daroca mine was later mapped by Sebastián de Rodophe in 1742²⁵ and repaired in 1790.²⁶ Vedel himself was a renowned sculptor and an architect active in Aragón in the 16th century. His projects mainly entailed religious buildings, but he was also involved in at least one other important hydraulic construction projects, the Acueducto de los Arcos, which brought drinking water to the town of Teruel in 1551–1558, again using mines to transfer the water.²⁷ The mine at Daroca is just one illustration of the range of hydraulic works carried out in Aragón and the rest of Spain in the 16th, some of which were only modest projects, whereas, others were large engineering enterprises promoted and developed by civic authorities working for the benefit of town communities.²⁸

23 Olcina Cantos 2012, 99–100; Mateos Royo 2005, 144–145; Almagro 1998.

24 Cock 1876, 28.

25 The map and profile are in the Archivo General de Simancas (MPD, 22, 067; MPD, 27, 042). Available at www.mcu.es (visited on 25/05/2018), under 'Ma-

terial cartográfico AGS'.

26 Forniés Casals 1980, 236.

27 Ibáñez Fernández 2005; Ibáñez Fernández 2006; Mateos Royo 2005, 143–144.

28 Mateos Royo 2005.

Another water feature that shares some characteristics with the *qanat* appears on the lower ground of the fluvial terraces; these are the filtration galleries called *cimbras* in Spanish, such as those in Granada (where documents already mention them in the 15th and 16th centuries)²⁹ and Almería province.

The *cimbras* are near-horizontal tunnels that lie beneath a watercourse, usually a dry riverbed or *rambla*, so that the rain and stream water percolates down. While the shortest of these tunnels may be 50–75 m in length, the longest are up to 13 km. Again, *cimbras* can have regular aeration shafts which may be circular or rectangular and are sometimes reinforced with dry-stone walling. Some of the tunnels are also dry-stoned and over 2 m high in some places, with variable widths depending upon geology and hydrology. Along the wider river courses, the *cimbra* is usually aligned at a diagonal to the course of the river and the water emerges on the lateral terraces; where the course of the river is narrow, the *cimbra* may criss-cross the river course in a zigzag, in order to maximize the potential for water filtration. However, not all *cimbras* have breather shafts and not all take their water exclusively from percolating stream water. Fig. 9 shows an example from Bulbiente, Zaragoza, where the water is captured first from a spring and then the flow is seasonally augmented by fluvial waters, as the *cimbra* runs beneath the stream bed of the River Huecha (dry for most of the year).

In addition, there are also *zanjas*, a variant of the *cimbra*, which are open trenches dug back into the water table, then covered with a lintel of flagstones and fluvial sediments. *Zanjas* have no breather holes, so to be cleaned the lintel stones have to be pulled up to enter the gallery below.

This wide range of different sorts of water galleries amply illustrates the problem of identification and definition. A similar range of technological or engineering features are always present, but they can be combined in different ways. If the defining characteristic of the *qanat* is that it should take its water from an aquifer, then *cimbras* must be excluded. Likewise, if breather shafts are a prerequisite, *zanjas* do not qualify. The same can be said of the Roman examples, at least in Spain, which in the cases we have examined, are either *adits* or simply part of a longer channel that sometimes runs under the ground and sometimes above it. Finally, it is also worthwhile stressing that this is a technology that was practiced until quite recently. In Murcia many of the identified examples seem to date to the second half of the 19th century and even early 20th, coinciding with a rise in population associated with lead, zinc, and silver mining, of which numerous archaeological structures of interest still remain. The boom in mining activity brought about an increased demand for vegetables and fruit and a need for more extensive irrigation. Many of these water galleries then fell out of use again in the second half of the 20th century when mining declined as a result of falling metal

29 Bertrand and Sánchez Viciana 2009, 155.



Fig. 9 *Cimbra* at Bulbunte, Zaragoza, running beneath the stream bed of the River Huecha.

prices and as intensive agricultural production for international markets led to water pumping and the lowering of water tables. This over-exploitation of the water resource has been made worse by the demand for urban water, massive tourism, and associated recreational facilities, such as swimming pools and golf courses.

4 A few case studies of the Spanish *qanat*

4.1 Madrid

Madrid means ‘place of *qanats*’ and, in all, some 124 km of *viajes de agua* have now been recorded beneath Spain’s capital. 70 km of water capture and 54 km convey water to the city, providing water to 750 fountains. These *qanats* vary in shape and size, some are unlined, others lined in brick with arched ceilings to improve their stability and prevent contamination; most are of a sufficient height for a person to walk inside them, about

60–80 cm wide.³⁰ Other notable details seen here are grooved floors with a conveyor channel to carry the water and permit pedestrian access alongside the channel. Some *qanats* also have large cisterns incorporated along their lengths to facilitate water storage and distribution, others have low ‘break dams’ along their course to slow down the rate of water flow, as well as smaller cisterns and checks that act to dissipate the current at corners. There are frequent breather shafts, every 40–50 paces, which are about 0.8 m in diameter and between 5 and 50 m deep. They are capped today with stones or brick covers.³¹

The origins of Madrid’s water network lie in the 9th century, when an Islamic water system was first developed in association with a fortress and later consolidated after the Christian reconquest of Toledo in 1083; at least one archaeological excavation has produced associated Islamic material. In 1561, Madrid became the capital of Spain. Its population grew considerably and, with it, there was increased demand for water. Documentary evidence indicates several new galleries were opened up at this time. The 17th century was the golden age of Madrid’s *qanats* and their water features: a dedicated ‘Fountain Committee’ (*Junta de Fuentes*) was created in 1617.³² An account from 1727 describes every gallery, every beneficiary, and public fountain.³³ The last branch was opened in 1855, at the same time as the dam Pontón de la Oliva, but by then, the system was under pressure, from an ever-increasing population and because of problems of quality and health, mainly due to groundwater contamination. These groundwater sources were the only source of water in the capital until 1858, when water from the River Lozoya was channelled and exploited, bringing water along the Canal de Isabel II. Many other points of interest could be noted, but one subtlety often seen in sophisticated water networks of this kind is the distinction made in contemporary documentation, for example in the 13th century, between *qanats* used for ‘fine’ or ‘coarse’ water; fine being used as drinking water and coarse for cleaning and irrigation.

4.2 Fuente Grande de Ocaña (Toledo)

The *qanat* at Ocaña is still in use today and supplies water to the village and its ‘Great Fountain’ (Fig. 10).

The fountain was built in 1573–1578, and is now a protected monument. Its design has been attributed to the famous Renaissance architect Juan de Herrera,³⁴ and although built in the style he is known for, the only documented builder is Francisco

30 López-Camacho 2002; Martínez-Santos and Martínez-Alfaro 2012.

31 Guerra Chavarino 2006; López-Camacho, Bustamante, and Iglesias 2005; Martínez Alfaro 1966; Martínez-Santos 2013; Oliver Asín 1959; Solesio de

la Presa 1975; Troll and Braun 1974.

32 Ardemens 1724.

33 Aznar de Polanco 1727.

34 López-Camacho, Bustamante, and Iglesias 2005.



Fig. 10 The 'Great Fountain' at Ocaña, Toledo, constructed in 1573–1578.

Hernández.³⁵ The underground infrastructure is thought to make use of Roman, Arab, medieval, and Renaissance elements, along a 400 m length of tunnels and well preserved vaulted chambers. Inserted into this system, there are rooms used for distribution, access, and to decant and clarify the water; these are all rendered in brick and considered to be contemporary with the construction of the 'Great Fountain'.

Like Madrid, other features of this system include conical caps (*madamas*) to the vertical shafts that are between 7 and 11 m deep, and 40 m apart; the caps are made of stone or brick with a central hole covered by a round stone. The floor of the gallery has a central raised path and two channels, just 30 cm wide, one on either side of the path, which allow for water of two different qualities to flow unmixed with one other. The superior quality water was used for human consumption, the worst for animals and washing clothes, etc. Once the water had reached the monumental stone fountain, it poured out through two taps (converted to ten in 1879) that faced a cobbled plaza some 1600 m square that could be accessed either by going down a ramp or two staircases. Alongside the taps, a stone trough was reserved for livestock and two further water troughs (*lavaderos*) were for use by up to 300 people for the washing of clothes, etc. Excess water was channelled from here beyond the square, and recycled for watering the local fields. Water had to be transported by hand from the square to the houses in the village until 1888, when water was elevated by a machine.³⁶

35 J. Rodríguez and Gascó Pedraza 1996.

Pavón Maldonado 1990.

36 López-Camacho, Bustamate, and Iglesias 2005;



Fig. 11 The *qanat* at Bureta, Zaragoza, includes: (A) a pond, (B) outlets for the *adit* and *qanat*, (C) shafts, plus (D) the mother well.

4.3 Bureta (Zaragoza)

Bureta is a very short *qanat*, only 164 m in length with 6 vertical access shafts, 20 to 28 meters apart, roughly one meter in diameter, ringed by upcast spoil on the surface (Fig. 11). A channel around 1.45 m high and 0.68 m wide runs seven meters below the ground and feeds water from the aquifer into a storage pond.

About 80 tons of fill would have been removed during its construction in all. Immediately adjacent is an *adit*, a horizontal tunnel with no vertical access shafts, which runs towards a local spring. This unlined tunnel is ca. 100 m long, 2.12 m high from its mud-choked base, and 0.9 m wide, with an inclined base and slightly rounded head (Fig. 12). Adze marks are still visible where the side faces have not fallen away.

The gradients of both the *qanat* and the *adit* are designed to intersect the surface as nearly as possible to an arrow-shaped storage pond, called the Albarquete, though the obvious differences in their construction imply that they are probably from a different date (Fig. 13). The pond, whose northern side is an earthen bund, retains the water before it is delivered down channels to a sub-circular area immediately to the north, traditionally an oasis of 33 hectares of irrigated land amid arid scrub pasture. Today, this tongue of irrigated land is almost a monoculture of vines, with some olive groves, but fifty years ago it provided maize, beetroot, alfalfa for grazing sheep, and market garden crops such as tomatoes.

In many respects, Bureta is typical of water infrastructure generally in Spain. Neither the *adit* nor the *qanat* are documented, there are no early maps, and the local archaeology is equivocal. A detailed field survey at high resolution has identified a late Iron Age site, a Roman villa and a number of Visigothic settlements, all within close proximity to the storage pond. None of these sites can be convincingly linked with either the *adit* or the *qanat* or indeed the natural spring site. Logic would suggest that the earliest settlement in the area was dependent upon the spring, whose flow was later augmented by the *adit*, possibly in Roman times. The chronology of the *qanat*, meanwhile, might be Islamic (i.e. 10th or 11th centuries in this region) or later. The fact that it is undocumented



Fig. 12 The *adit* at Bureta is some 100 m long, 2 m high and 0.9 m wide.



Fig. 13 The unlined tunnel in the *qanat* at Bureta, Zaragoza.



Fig. 14 Sections cut through the spoil at the top of the breather shafts at the *qanat* in Bureta, in order to collect samples for OSL.

suggests that it cannot be recent (Fig. 14).

5 Dating

Qanats and other water features are in general difficult to date in their own right. As we have seen above, in the case of Citruénigo, some *qanats* already have a documented date of construction. The vast majority, however, cannot be directly dated and the archaeologist must use proxies of one sort or another. The first of these is to identify an associated monument or settlement which can itself be dated by other means. One example here is the system linked to the cave dwellings at Las Hafas, Benamaurel (Granada), which is dated to the end of the 12th century, providing a date for the use of the gallery.³⁷ It is, however, rare to find settlements of a single period or clearly defined date and, as in

37 Bertrand and Sánchez Viciana 2009.

the case of the *qanat* at Ocaña, the construction date of the existing fountain does no more than provide a *terminus ante quem* for the system as a whole. Detailed archaeological field survey information can also sometimes help. When archaeological materials, particularly pottery, are collected field-by-field on a timed system of survey, it is possible to produce mapped densities which can be compared against the arable spaces irrigated by each irrigation channel or *acequia*. In theory, the abundance of sherds should indicate the irrigated areas at different periods. It might reveal, for example, the spatial relationship between Roman sites and the irrigation network. There are other indirect proxies for irrigation too, among them: the development of plant seeds; the increased deposition of silica in cereal plants when they grow under irrigation; and the presence of weeds which are sensitive to irrigation practice.³⁸ As previous Spanish studies for Bronze Age and Neolithic sites have demonstrated,³⁹ carbon isotope discrimination is also affected by water availability and one aim would be to analyze carbon isotopes in cereals from late Roman, Islamic, and later medieval contexts from a set of archaeological sites in one region where the hydraulic network is well understood.

Difficulties in dating also derive from the repair and reuse of older systems. In most recent repairs there is little interest in either recording or preserving the original features that are often altered to include concrete mouths, cement caps, the rebuilding of access, and interiors, etc. Alterations themselves can also be old. Roman underground galleries were reused in the Islamic period, including those feeding water to Seville and Córdoba, for example. In the first case, Roman Seville received its water from a system that drew water off springs at Alcalá de Guadaira, some 17 km away. The channeling of water began here as an underground gallery with shafts opening every 80–100 m, then the water came to the surface in channels built over walls, and finally in a proper aqueduct that had over 400 arches, bridging more than 4 km. The water arrived in Seville at what was later called the Caños de Carmona to the north of the city. A chronicle describes how in 1189 an Almohad engineer uncovered and dug out the system, recognized it to be a *qanat*, had it repaired, built a branch to feed the Bohaira Palace, and then constructed a cistern to store the water.⁴⁰ Another example is the aqueduct that brought water to the Islamic palace of Madinat al-Zahra and to Córdoba. Early references to the 16th century suggest that whole system is Islamic, given that the last recorded works dated to this period. In the 16th century, for example, Morales described the good stonework and the interior render of red mortar on top of pitch, together with the shafts or breathing holes (*lumberas*), made to “avoid the tunnel collapsing.”⁴¹ It is only much later that two

38 For example Bogaard et al. 2007.

39 For example Araus and Buxó 1993.

40 Fernández Casado 1970; Ibn Sāhib al-Salāt 1969, 190–191; Jiménez Martín 1975; Montes Romero-

Camacho 1993; Carrasco Gómez and Jiménez Hernández 2008.

41 Morales 1575, 124v–125.

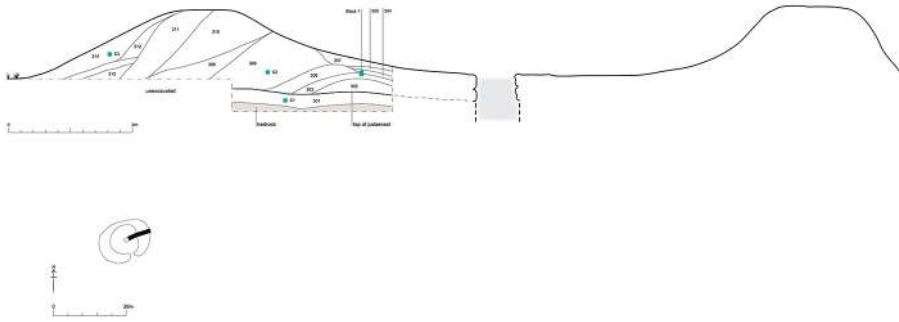


Fig. 15 North-facing section excavated through one of the mounds at Jumilla, Murcia (Mound 3), showing the stratigraphy, location of the samples for OSL and the palaeosol.

building episodes were identified: Roman and Islamic.⁴² The first system, known as Valdepuentes, was built during the Roman period in 27 BC–AD 14; with a total length of 42 km, it includes sections of aqueduct as well as underground galleries with 40 shafts, some of them with decanting pits, and all finished with prismatic turrets and capped with a flat stone. When this collapsed after an earthquake, the hydraulic system was rebuilt with new branches in the middle of the 3rd century, and later reused in the 10th century by the Arabs.⁴³

Another technique, now being experimented with, is dating through optically stimulated luminescence (OSL). A Leverhulme Trust project involving a team from Durham and Winchester Universities (UK)⁴⁴ has been sampling the episodes of upcast around the mouths of breather shafts at a selection of sites, including Jumilla and Totana (both Murcia; Figs. 15 and 16) and on the west coast of sub-Saharan Morocco, where a series of archaeological sites associated with *cimbras* are being investigated by joint Spanish and Moroccan teams.⁴⁵ Further fieldwork is planned in Oman and the United Arab Emirates later in 2016. These sites have been selected only after preliminary testing of the sediments demonstrated that they would be suitable for dating using OSL and where the permission of local authorities and landowners could be obtained.

One set of results is now available for Bureta (Zaragoza), where three mounds of upcast were sampled. Two of these produced younger dates than expected, quite possibly due to the weathering and slumping process that has eroded the mounds and the lip of the shaft.⁴⁶ Mound 2, however, produced evidence for three phases of upcast made up

42 Cean-Bermúdez 1832, 341.

43 Moreno et al. 1997; Ventura Villanueva 1993; Ventura Villanueva 2002; Ventura Villanueva and Pizarro Berengena 2010.

44 “Developing new approaches to dating ancient irri-

gation features”, <https://www.dur.ac.uk/archaeology/research/projects/all/?mode=project&id=752> (visited on 25/05/2018).

45 Onrubia Pintado et al. 2014.

46 Bailiff et al. 2015.

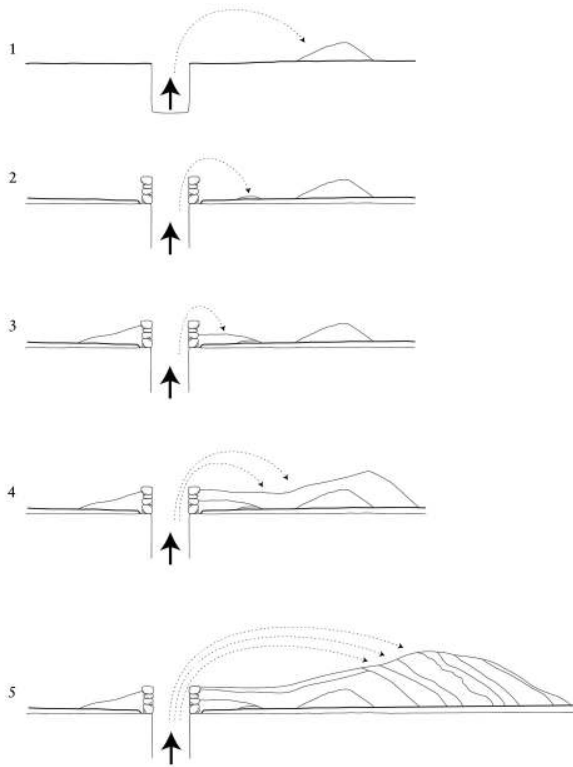


Fig. 16 An interpretation of mound formation for Mound 3 at Jumilla (see Fig. 15).

of loose, poorly sorted, clay aggregates, sandstone, and mudstone. Occasional fine roots were also present where a more humic layer had built up, presumably following an episode of cleaning. These three layers lay above a compact silty palaeosol. The OSL dates for the basal deposits from two samples from this mound are in agreement with each other, and they place construction in the first half of the 13th century. The key dates are 1230 ± 70 and 1310 ± 65 with a first phase of cleaning in the 15th century. This *qanat* is, therefore, not Islamic but would seem to date to a period at least 100 years after the Christian conquest of the region in ca. 1118. It would seem that it was not in the interests of the new Christian authorities to disrupt farming, quite the opposite in fact; higher rents could be demanded from better irrigated land and where re-settlement demanded it, and new irrigation systems were a fundamental investment.

6 Conclusion

We are beginning to perceive a rather more complex picture of *qanat* chronology in the western Mediterranean but, as yet, we are not exactly sure where this new understanding will take us. In the Arabian Peninsula, archaeologists now claim *qanats* from the early first millennium,⁴⁷ though some doubt has been cast on the precision of the dating of the pottery which provides these dates.⁴⁸ In Egypt, the evidence is more convincing, with finds and the recording of water rights suggesting that *qanats* were present by the mid-5th century BC, while in the Libyan Sahara at Fazzān, a late first millennium date (2nd century BC–4th century AD) has been suggested for the *foggara* there on the basis of their spatial and stratigraphical relationship to archaeological features of better known date (e.g. stone tumuli, settlement sites dated by pottery) and other accumulated evidence including archaeobotany which suggests irrigated crops.⁴⁹ Assuming diffusion into Roman North Africa, it is no surprise to find these various elements of *qanat* technology in a Roman Spanish context, although no independently dated examples of true *qanats* are known to these authors from Roman Spain and, even when there is plentiful evidence for Roman irrigation projects, for example around Valencia, questions of population and economic crises in the 5th and 6th centuries put any direct continuity of practice in doubt.

The Arab contribution is undeniable in enhancing hydraulic practices, intensifying them, and spreading them across al-Andalus after the 8th century; these were the multiple small-scale solutions that transformed a landscape. Arab texts seemingly provide conclusive proof that *qanat* technology was known in al-Andalus in AD 753–754, but even here the paucity of documentation is a problem and the institutional and technological aspects of Islamic irrigation tend to be examined from subsequent Christian documents (such as litigations and regulations) or by archaeologists for whom, as we have seen, dating is a major issue. Certainly, there were further changes to hydraulic networks following the Christian conquest, as the Bureta example seems to illustrate, and it is even possible that some developments in Spain were influenced by practises on the other side of the Atlantic by the end of the 16th century. It is difficult to talk with any conviction about the transmission of an Islamic technological package to the New World (for one thing, Spain is simply not the same cultural entity in the 15th century as it was 700 years previously). So, the picture that emerges is not one of linear development but of continuous reinvention and adaption of a successful and simple engineering technology in response to local pressures of population and the demand for

47 Magee 2005.

48 Wilson 2008.

49 Wilson and Mattingly 2003.

cultivation. The vast majority of true *qanats* in Spain are probably 16th–19th century in date.

‘Hydropolitics’ is a hugely contentious issue in Spain; in October 2000, 400 000 people demonstrated in Zaragoza against the government’s National Water Plan, which proposed a diversion of the River Ebro to the Mediterranean coast. This is a country in which ancient irrigation systems compete all the time with urban land uses, and no country in Europe has lost such a high proportion of its highest quality soils due to urbanisation. Traditional systems like *qanats* are said by some to be unsustainable and inefficient; local tensions run high. Water is heavily subsidized, but maize, alfalfa, and other crops unsuitable to the local climate simply could not be farmed at a profit without financial help. As yet, to treat *qanats* and other hydraulic features as a heritage worth conserving and protecting on a par with palaces and castles is a step too far for many.

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